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Date of mailing (day/month/year)

21 June 2000 (21.06.00)

International application No.

PCT/AU99/01000

Applicant's or agent's file reference

IHA:FP11653

International filing date (day/month/year)

12 November 1999 (12.11.99)

Priority date (day/month/year)

12 November 1998 (12.11.98)

Applicant

CANNING, John

1. The designated Office is hereby notified of its election made:



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**Optical Device and Process**Field of the invention

The present invention relates broadly to an optical device comprising a waveguide and a process for fabricating the same.

Background of the invention

In optical waveguides it is often desirable to direct light around bends, for example to reduce the size of devices incorporating optical waveguides. An inherent problem is, however, that due to the refractive index properties of the waveguide and the material surrounding the waveguide, it is likely that light will be diffracted out of bends, in particular tight bends, thereby resulting in what is commonly referred to as bending losses. Such losses can limit the performance of the device.

The directing of light signals in different directions would also be desirable in devices where it is required to confine light to a predetermined path within the waveguide, for example in optical filter or optical resonator structures.

Summary of the Invention

The present invention provides an optical waveguide structure comprising:

- an optical waveguide having a bend and being formed of a photosensitive material; and
- a grating structure arranged to guide light of a predetermined wavelength around the bend in the waveguide, the grating structure comprising UV-induced refractive index variations in the waveguide.

A substantial reduction in bending loss can be achieved by guiding light around the bend with the grating structure.

The present invention allows for angular dispersion to be added to a propagating light signal which can be controlled by the properties of the grating structures.

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For example, this can be utilised for dispersion compensation, pulse shirping, or pulse compressing. This is because different wavelengths see a different angular path with respect to the grating structure.

5       The device may be utilised in complex light manipulation circuits both in the spectral and time domain.

      The grating structure may comprise a chirped grating.

      The grating structure may be disposed to direct the light in a reflection or in a transmission mode.

10       Because of an angular dependence of the accepted wavelength in the grating, the device can depend on angular sweep to isolate wavelengths or signals.

      The grating structure may comprise a continuous grating. Alternatively, the grating structure may comprise  
15       two gratings which mirror each other.

      In one embodiment, the grating structure comprises regions of constant refractive index which extent in the propagation direction of the waveguide.

      The regions may extend parallel to the propagation  
20       direction.

      The regions may extend cylindrically parallel to the propagation direction.

      The regions may extend ellipsoidally parallel to the propagation direction.

25       The device may further comprise at least one optical reflector disposed in a direction transverse to the propagation direction to aid in confining the light to the path.

      The device may comprise two or more grating structures  
30       angularly disposed with respect to each other to guide light around the bend.

      Accordingly, different confinement conditions may be realised at different boundaries of the waveguide.

      The grating structures may be formed by UV-holography.

35       The gratings may be chirped gratings.

      The gratings may be sampled gratings.

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The device may be a filter, a resonator, or a sensor.

In one embodiment, the device is a sensor further comprising means for measuring an intensity of the light at a predetermined point along the waveguide for determining  
5 changes in the intensity due to induced changes in confinement conditions of the sensor.

The changes may be induced by gas molecules entering the waveguide.

The present invention may alternatively be defined as  
10 providing a method of adapting a photosensitive waveguide to guide light of a predetermined wavelength around a bend in the waveguide, comprising:

- using UV light to induce refractive index variations in the waveguide such that at least one grating structure is  
15 formed, wherein the grating structure is disposed to guide the light around the bend.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

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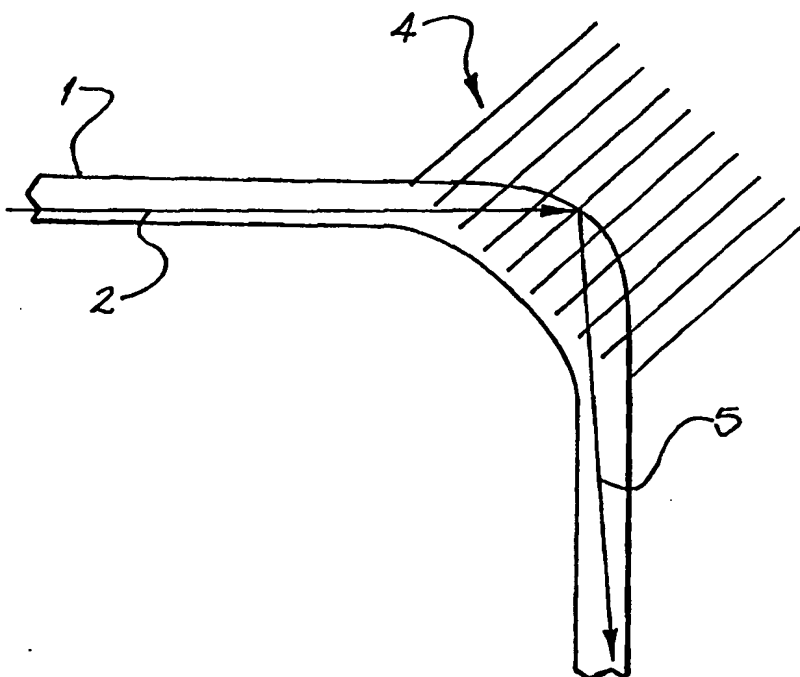
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification</b> <sup>6</sup> : <b>G02B 6/18, 6/10, 5/26, 5/28, 5/18</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 00/29883</b> <b>(43) International Publication Date:</b> 25 May 2000 (25.05.00)
<b>(21) International Application Number:</b> PCT/AU99/01000 <b>(22) International Filing Date:</b> 12 November 1999 (12.11.99)  <b>(30) Priority Data:</b> PP 7168 12 November 1998 (12.11.98) AU PQ 2503 27 August 1999 (27.08.99) AU  <b>(71) Applicant (for all designated States except US):</b> THE UNIVERSITY OF SYDNEY [AU/AU]; Parramatta Road, Sydney, NSW 2006 (AU).  <b>(72) Inventor; and</b> <b>(75) Inventor/Applicant (for US only):</b> CANNING, John [AU/AU]; 10 Francis Street, Carlton, NSW 2218 (AU).  <b>(74) Agent:</b> GRIFFITH HACK; G.P.O. Box 4164, Sydney, NSW 2001 (AU).		<b>(81) Designated States:</b> AU, CA, JP, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>

**(54) Title:** OPTICAL WAVEGUIDE STRUCTURE

**(57) Abstract**

An optical device comprising a waveguide structure (1), at least one grating structure (4) formed in the waveguide structure, and the grating structure being disposed to direct along a selected path (5) in the waveguide structure light of a predetermined wavelength entering the waveguide structure at a predetermined angle of incidence to the grating structure.



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## Optical Device and Process

### Field of the invention

The present invention relates broadly to an optical device comprising a waveguide and a process for fabricating the same.

### Background of the invention

In optical waveguides it is often desirable to direct light around bends, for example to reduce the size of devices incorporating optical waveguides. An inherent problem is, however, that due to the refractive index properties of the waveguide and the material surrounding the waveguide, it is likely that light will be diffracted out of bends, in particular tight bends, thereby resulting in what is commonly referred to as bending losses. Such losses can limit the performance of the device.

The directing of light signals in different directions would also be desirable in devices where it is required to confine light to a predetermined path within the waveguide, for example in optical filter or optical resonator structures.

### Summary of the Invention

The present invention provides an optical device comprising a waveguide structure, at least one grating structure formed in the waveguide structure; the grating structure being disposed to direct along a selected path in the waveguide structure light of a predetermined wavelength entering the waveguide structure at a predetermined angle of incidence to the grating structure.

As the light directing is achieved by utilising the grating structure, a substantial reduction in bending loss can be achieved.

The waveguide structure may be formed from photosensitive material, and the grating structure may be formed by UV-induced refractive index variations in the waveguide.

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The present invention allows for angular dispersion to be added to a propagating light signal which can be controlled by the properties of the grating structures. This can be utilised for e.g. dispersion compensation, pulse shirping, or pulse compressing. This is because different wavelengths see a different angular path with respect to the grating structure.

The device may be utilised in complex light manipulation circuits both in the spectral and time domain.

10 The grating structure may comprise a chirped grating.

The grating structure may be disposed to direct the light in a reflection or in a transmission mode.

The present invention may alternatively be defined as providing an optical device comprising a waveguide of photosensitive material; at least one grating structure formed by UV-induced refractive index variations in the waveguide; the grating structure being disposed to confine to a selected path in the waveguide light of a predetermined wavelength entering the waveguide at a predetermined angle of incidence to the grating structure.

Because of the angular dependence of the accepted wavelength in the grating confined waveguide such devices can e.g. depend on angular sweep to isolate wavelengths or signals.

25 The grating structure may comprise a continuous grating. Alternatively, the grating structure may comprise two gratings which mirror each other.

In one embodiment, the grating structure comprises regions of constant refractive index which extent in the propagation direction of the waveguide.

30 The regions may extend parallel to the propagation direction.

The regions may extend cylindrically parallel to the propagation direction.



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The regions may extend elipsoidically parallel to the propagation direction.

The device may further comprise at least one optical reflector disposed in a direction transverse to the  
5 propagation direction to aid in confining the light to the path.

The device may comprise two or more grating structures angularly disposed with respect to each other to channel the light around the selected path.

10 Accordingly, different confinement conditions may be realised at different boundaries of the waveguide.

The grating structures may be formed by UV-holography.

The gratings may be chirped gratings.

The gratings may be sampled gratings.

15 The device may be a filter, a resonator, or a sensor.

In one embodiment, the device is a sensor further comprising means for measuring an intensity of the light at a predetermined point along the selected path for  
determining changes in the intensity due to induced changes  
20 in confinement conditions of the sensor.

The changes may be induced by gas molecules entering the waveguide.

The present invention may alternatively be defined as providing a process for fabricating an optical device  
25 comprising a waveguide of photosensitive material, the method comprising the step of forming at least one grating structure by UV-induced refractive index variations in the waveguide; the grating structure being disposed to confine to a selected path in the waveguide light of a  
30 predetermined wavelength entering the waveguide at a predetermined angle of incidence to the grating structure.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Brief Description of the Drawings

Figure 1 is a schematic drawing of a device embodying the present invention.

Figure 2 is a schematic drawing of a device embodying the present invention.

Figure 3 is a schematic drawing of a device embodying the present invention.

Figure 4 is a schematic drawing of a device embodying the present invention.

Figure 5 is a schematic drawing of a device embodying the present invention.

Figure 6 illustrates in an isometric view a method of fabricating a grating confined waveguide embodying the present invention.

Figure 7 illustrates in an isometric view another method of fabricating a grating confined waveguide embodying the present invention.

Figure 8 is a schematic drawing in a cross-sectional view illustrating a device embodying the present invention.

Figure 9 is shows a plot of resonant angle against grating period for a grating confined waveguide.

Figure 10 is a schematic drawing in an isometric view illustrating a device embodying the present invention.

Figure 11 is a schematic drawing in a top view illustrating a device embodying the present invention.

Figure 12 is a schematic drawing in a cross-sectional side view illustrating a device embodying the present invention.

Figure 13 is a schematic drawing in an isometric view of a resonator structure embodying the present invention.

Figure 14 is a schematic drawing in an isometric view of a device embodying the present invention.

Detailed Description of the Preferred Embodiments

Turning initially to Fig. 1, there is illustrated schematically a first example embodiment wherein a

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waveguide 1, down which light 2 is to be projected, undergoes a tight bend in the desired path. In the vicinity of the tight bend, a grating structure 4 is written. The grating structure 4 effectively has a photonic band gap preventing the effervescent light 2 from leaking out and resulting in higher efficiency in the light coupled to output 5. This results in a substantial reduction in the bending loss as a result of the utilization of the defraction grating 4 which in turn allows for tighter bends to be formed in the waveguide structure. The wavelength of the grating 4 can be tuned so as to match desired frequencies for operation.

Alternatively, as illustrated in Fig. 2, the grating 6 can be written in a reflection mode so as to provide for reflection of desired frequencies along the path 7 with losses 8 for those frequencies not having desired characteristics.

The utilization of the arrangement of Fig. 2 can be extended so as to provide for wavelength division multiplexing capabilities on a waveguide structure. This is illustrated in Fig. 3 wherein initial light can be launched down a waveguide having a number of frequencies  $\lambda_1$ ,  $\lambda_2$ ,  $\lambda_3$  coupled out of the waveguide by utilization of corresponding matched Bragg gratings 12, 13, 14 which operate so as to filter out the requisite frequencies.

Fig. 4 illustrates a further arrangement whereby light coupled along waveguide 15 will be coupled to outputs 16, 17 by means of suitably matched Bragg grating 18 having desired periodic characteristics, matched to the desired frequencies for coupling. The surrounding waveguide refractive index regions eg. 19 can be tapered to provide for stronger coupling. Preferably, the splitter arrangement of Fig. 4 has a Bragg grating coupled such that 50% of the light traverses along each of path 17, 18. This can be achieved for wavelengths twice the Bragg period. Of course, it is possible to adjust the Bragg period to adjust the output angle and coupling efficiency.

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Similarly, in Fig. 5 a Bragg grating 20 is provided for coupling around a bend for light travelling along the path 21, 22.

5 In Figure 6, a waveguide 110 in the form of a layer of photosensitive material has been deposited onto a substrate 112, eg. a silicon wafer having a native oxide layer for optical isolation of the waveguide material 110.

A UV beam 116 from a UV source 114 is focussed  
10 (through optical elements 118) in the plane of the waveguide 110. The substrate 112 can be laterally moved as indicated by arrows 120 and 122 to effect writing of planes indicated by lines 124 of a first grating 126 of a grating structure 127, through UV-induced changes of the refractive  
15 index of the waveguide 110.

After completion of the first grating 126, a second grating 128 of the grating structure 127 is written by appropriate moving of the substrate 112.

Light of a predetermined wavelength entering the  
20 waveguide 110 at predetermined angles of incidence on the gratings 126, 128 are confined to a path extending in the propagation direction 130 in the plane of the waveguide 110. The propagation characteristics of the waveguide 10 will therefore depend on the wavelength of a light signal  
25 131 and an angle  $\theta$  under which it enters the waveguide 110.

It is noted here, that in the planar structure described above the grating confinement is limited to one-dimension in the plane of the waveguide 110. However, it will be appreciated that waveguides can be produced in a  
30 photosensitive waveguide material that are grating confined in two or three dimensions.

For example, as illustrated in Figure 7, holographic UV grating writing techniques using a phase mask 140 can be used to produce a waveguide 142 (propagation direction as  
35 indicated by arrow 141) within a block 144 of

photosensitive waveguide material which is grating confined in two dimensions through gratings 146, 148 of a first grating structure 147 and gratings 150, 152 of a second grating structure 151 respectively.

5 It is noted that the one or more of the grating structures of a device could alternatively comprise a continuous grating whilst still effecting confinement of light of a predetermined wavelength entering at a predetermined angle of incidence on the grating structure.

10 E.g. the resonator 250 shown in Figure 14 comprises two continuous grating structures 252, and 254 to effect channelling of light 256 of a predetermined wavelength entering the resonator 250 at a predetermined angle of incidence on the grating structures 252 and 254 around a  
15 ring path 258.

Grating confinement can also be achieved in an optical fibre, e.g. using a cylindrical grating structure 320 around a guiding core 322 (propagation direction perpendicular to the drawing plane) of an optical fibre 324  
20 as illustrated in Figure 12. The grating structure 320 effects confinement to a path extending in the propagation direction of light of a predetermined wavelength entering at a predetermined angle of incidence on the grating structure 320.

25 It will be appreciated by a person skilled in the art that for a non-cylindrical grating structure confinement conditions can vary in different radial directions.

The underlying principle of grating confined waveguide propagation is the Bragg condition. For a ray travelling  
30 in a medium of index  $n$ , peak reflectivity occurs when the wavelength  $\lambda$  satisfies:

$$\lambda = 2n\Lambda \sin \theta / m \quad (1)$$

where  $m$  is the diffraction order of the grating and  $\theta$  is the angle of the ray with respect to a single groove of  
35 the grating. This single equation contains within it the

entire properties of grating confinement such as e.g. so-called photonic crystal fibres.

Figure 8 shows the plot of resonant angle against grating period for the wavelength regime 1200-1600 nm for 1st, 2nd and 3rd order grating diffraction. At longer periods, variations in the resonant angle converge to within a few degrees, although the effect is largest for the 1st order. The physical interpretation is that for a large number of wavelengths the incident angle is approximately the same equating with similar diffraction properties. Therefore grating confinement will occur over a large bandwidth for a small input coupling angle at longer periods under identical launch conditions. Outside this regime radiation loss will occur.

Other interesting properties are noted. There exist other regimes of incident angle at which total internal reflection can occur to enable propagation along the grating confined waveguide. Light coupled into higher diffraction orders at much larger incident angles can also satisfy the Bragg relation, giving rise to higher order bandgaps. The effective coupling strength is reduced for higher order mode propagation in these regimes and is therefore characterised by larger mode areas. Since the effective index is different, it is possible to have fundamental-like mode behaviour simultaneously with different propagation properties. Thus e.g. photonic fibres have interesting launch regimes which are unlike conventional effective index fibres. These regimes exist because there are angular photonic bandgaps at which light cannot propagate through the surrounding grating cladding. Further, these bandgaps are robust and do not change much in angular properties with increasing period and will therefore be relatively insensitive to bend loss at longer periods.

The angular photonic bandgap is described by the angular reflectivity of the grating. This reflectivity bandwidth can be extremely small, depending upon the dimensions of the grating, its coupling coefficient, and the angle of incidence. For either normal (incident angle,  $\theta = 90^\circ$ ) or angled incidence, the power reflectivity is given from coupled mode theory as

$$R = \left| \frac{K \sinh SL}{S \cosh SL + i\Delta\beta \sinh SL} \right|^2 \quad (2)$$

where

$$S \equiv \sqrt{K^2 - (\Delta\beta)^2} \quad (3)$$

K is the angle-dependent coupling coefficient for the grating, L is the length of the grating and  $\Delta\beta$  is the detuning of the wavevector, defined by

$$\Delta\beta = \frac{m\pi}{\Lambda} - \frac{2\pi n}{\lambda} \sin \theta \quad (4)$$

Peak reflectivity occurs for  $\Delta\theta = 0$  and declines as  $\Delta\theta$  exceeds the magnitude of K. It is readily shown in grating confined waveguides that the angular acceptance of the reflectivity narrows considerably, with deviation away from near normal incidence (as indicated by the decreasing slope of Figure 8). Consequently, the higher order photonic bandgaps will be broader and less spatially selective and this may have implications for the robustness of singlemode operation for large input angles. The variation of detuning  $\delta(\Delta\beta)$  with angle  $\delta\theta$  is easily calculated from above:

$$\frac{\delta(\Delta\beta)}{\delta\theta} \approx -\frac{2\pi n}{\lambda} \cos \theta \quad (5)$$

From this sensitivity to the capture angle it is possible to vary the angular dispersion significantly by appropriate selection of the period. Since the angle of incidents are similar at longer periods (Figure 8) the

propagation constants, and therefore the sensitivity to capture angle, tend to converge with increasing grating period - it is therefore possible to achieve a dispersion flattened profile of the type found numerically.

5       Note that even for light guided solely under the effective index picture when the core index is higher than the surrounding cladding, unless the mode vector has an angle resonant with that of the grating, light can quickly couple to radiation modes and leak out. Further, this  
10       intolerance to the mode angle gives rise to the high spatial selectivity of these angular bandgaps such that single-moded propagation is robust especially for long grating periods. The mode profiles that are supported will therefore resemble the geometric positioning of the  
15       gratings radially around the core region and should differ from conventional waveguide guidance where such strict restrictions do not exist.

By recognising the importance of diffraction in a periodic lattice it is easily shown that grating confined  
20       propagation is readily achieved in so-called photonic crystal fibres. Further, the associated angular photonic bandgaps are responsible for a range of phenomena that distinguish these fibres from conventional effective index fibres. Extending the applications to resonators made up  
25       of these fibres, very interesting behaviour is predicted to occur as a result of the strict vector angles of the propagating modes, including ring-like resonances when the end reflectors are tilted. The polarisation properties of such structures may also differ to conventional resonators  
30       and an entire new class of passive and active filters and resonators are possible.

In Figure 9, a resonator 181 can be utilised for WDM (wavelength division multiplexing) filtering if the grating periods (which may be chirped) of gratings 182 and 184 of a  
35       first grating structure 183 and of gratings 186 and 188 of



a second grating structure 187 are carefully selected such that a ring resonance is different for different wavelengths and therefore the outputs are spatially at different points. This is schematically illustrated by paths 190, 192 and example outputs 194, 196. The grating structures 183 and/or 187 may be sampled grating structures.

Complex design with the use of sampled profiles etc. can be used to achieve WDM operation. In particular the angular dependence means that it may be possible to get much more closely spaced peaks with higher contrast than conventional normal incidence. It is noted that this is also applicable to fibre (e.g. photonic crystal fibres) geometries.

As illustrated in Figure 10, in a resonator laser design 300 a photonic crystal fibre 302 is located in line in a ring laser 304 (of any sort) to improve both linewidth, laser stability and mode selectivity (including transverse if multi-mode active fibre is used to increase power). It is noted that a similar design can be applicable to linear lasers (of any sort).

As illustrated in Figure 11, in an alternative embodiment, a helical ring fibre laser 310 comprises an optical fibre 312 having a grating confined core structure 314 and spaced apart concave reflectors 315, 316 within the core structure 314. The helical ring fibre laser 310 can thus provide a circularly birefringent output (as indicated by arrow 311).

Furthermore, high power fibre lasers may be provided without using cladding pump configuration. For such lasers, single mode operation and good stability are possible, as well as large mode areas. In such embodiments, the modes are grating diffraction dependent unlike conventional fibres which are aperture diffraction dependent.

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It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present  
5 embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

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The claims defining the invention are

1. An optical device comprising:

- a waveguide structure;
- at least one grating structure formed in the

5 waveguide structure; and

the grating structure being disposed to direct along a selected path in the waveguide structure light of a predetermined wavelength entering the waveguide structure at a predetermined angle of incidence to the grating  
10 structure.

2. A device as claimed in claim 1, wherein the waveguide structure is incorporates a photosensitive material, and the grating structure is formed by UV-induced refractive index variations in the photosensitive material.

15 3. A device as claimed in any one of the preceding claims, wherein the grating structure comprises a chirped grating.

4. A device as claimed in any one of the preceding claims, wherein the grating structure comprises a sampled  
20 grating.

5. A device as claimed in any one of the preceding claims, wherein the grating structure is disposed to direct the light in a reflection mode.

6. A device as claimed in any one of the preceding  
25 claims, wherein the grating structure is disposed to direct the light in a transmission mode.

7. An optical device comprising:

- a waveguide of photosensitive material;
- at least one grating structure formed by UV-induced

30 refractive index variations in the waveguide; and

the grating structure being disposed to confine to a selected path in the waveguide light of a predetermined wavelength entering the waveguide at a predetermined angle of incidence to the grating structure.

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8. A device as claimed in claim 7, wherein the grating structure comprises a continuous grating.

9. A device as claimed in any one of claims 7 to 8, wherein the grating structure may comprise two gratings which mirror each other.

10. A device as claimed in any one of claims 7 to 9, wherein the grating structure comprises regions of constant refractive index which extend in the propagation direction of the waveguide.

11. A device as claimed in claim 10, wherein the regions extend parallel to the propagation direction.

12. A device as claimed in claim 11, wherein the regions may extend cylindrically parallel to the propagation direction.

13. A device as claimed in claim 11, wherein the regions may extend ellipsoidically parallel to the propagation direction.

14. A device as claimed in any one of claims 7 to 13, wherein the device further comprises at least one optical reflector disposed in a direction transverse to the propagation direction to aid in confining the light to the path.

15. A device as claimed in any one of claims 7 to 14, wherein the device comprises two or more grating structures angularly disposed with respect to each other to channel the light around the selected path.

16. A device as claimed in any one of claims 7 to 15, wherein the grating structure or structures are formed by UV-holography.

17. A device as claimed in any one of claims 8 to 16, wherein the grating or gratings are chirped.

18. A device as claimed in any one of claims 8 to 17, wherein the grating or gratings are sampled.

19. A device as claimed in any one of claims 7 to 18, wherein the device is a sensor further comprising means for

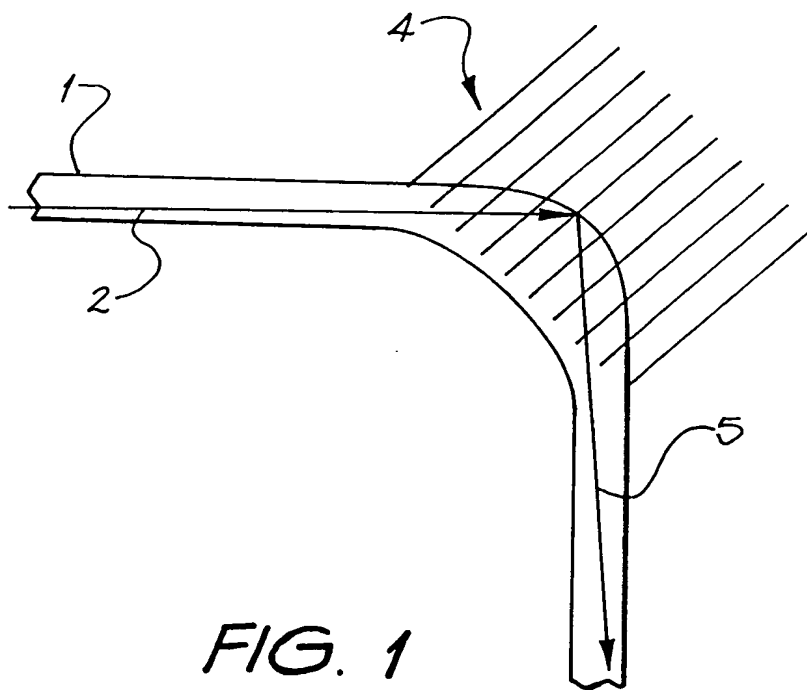
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measuring an intensity of the light at a predetermined point along the selected path for determining changes in the intensity due to induced changes in confinement conditions of the sensor.

5           20. A process for fabricating an optical device comprising a waveguide of photosensitive material, the method comprising the step of:

          - forming at least one grating structure by UV-induced refractive index variations in the waveguide; and

10           the grating structure being disposed to confine to a selected path in the waveguide light of a predetermined wavelength entering the waveguide at a predetermined angle of incidence to the grating structure.



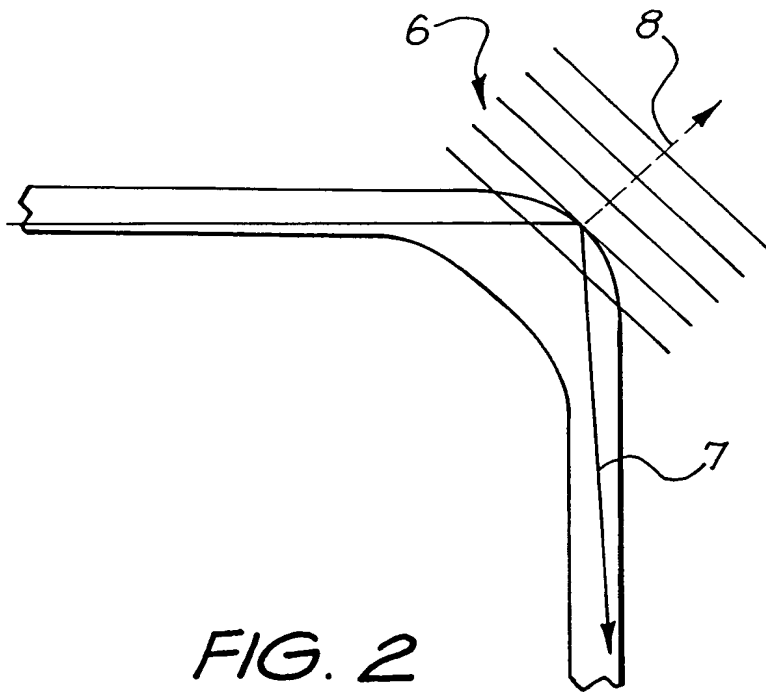


FIG. 2

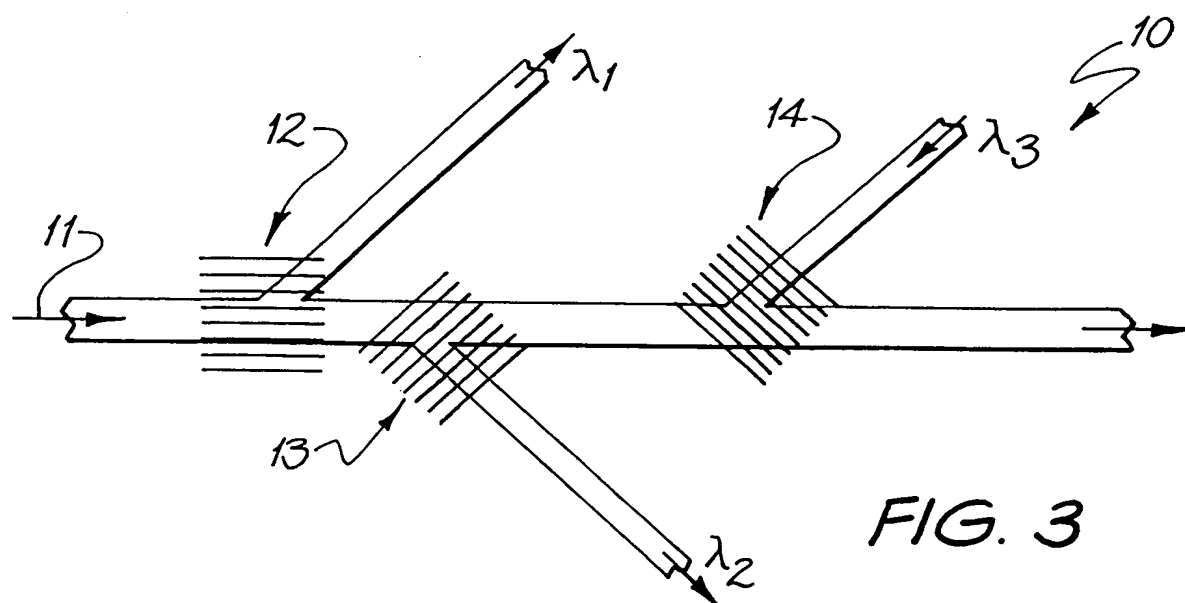


FIG. 3

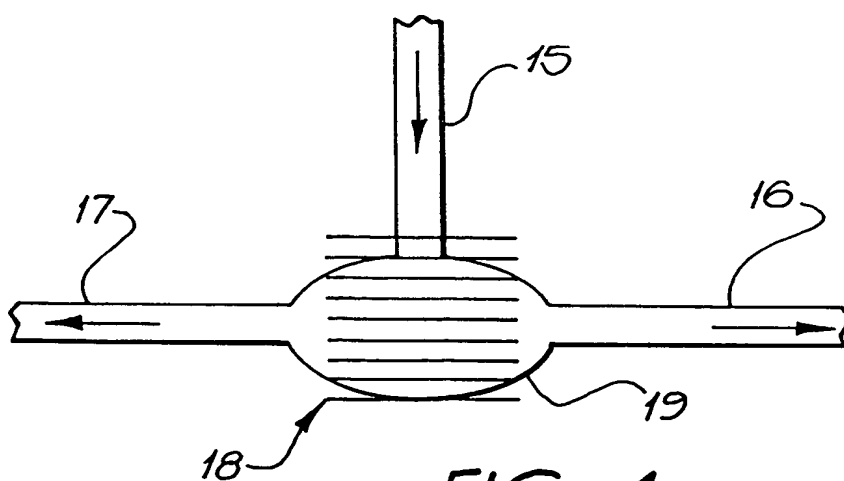


FIG. 4

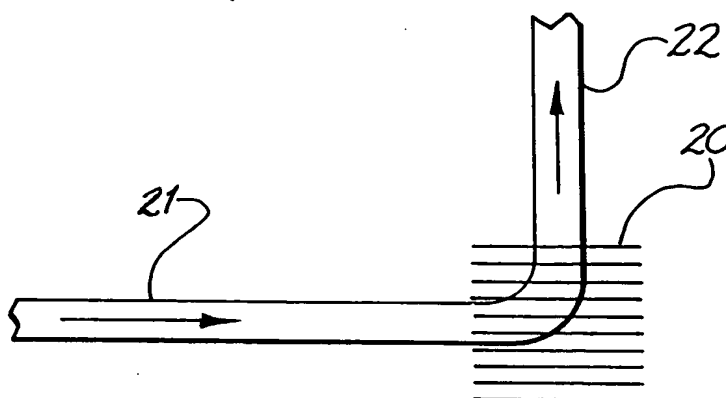


FIG. 5



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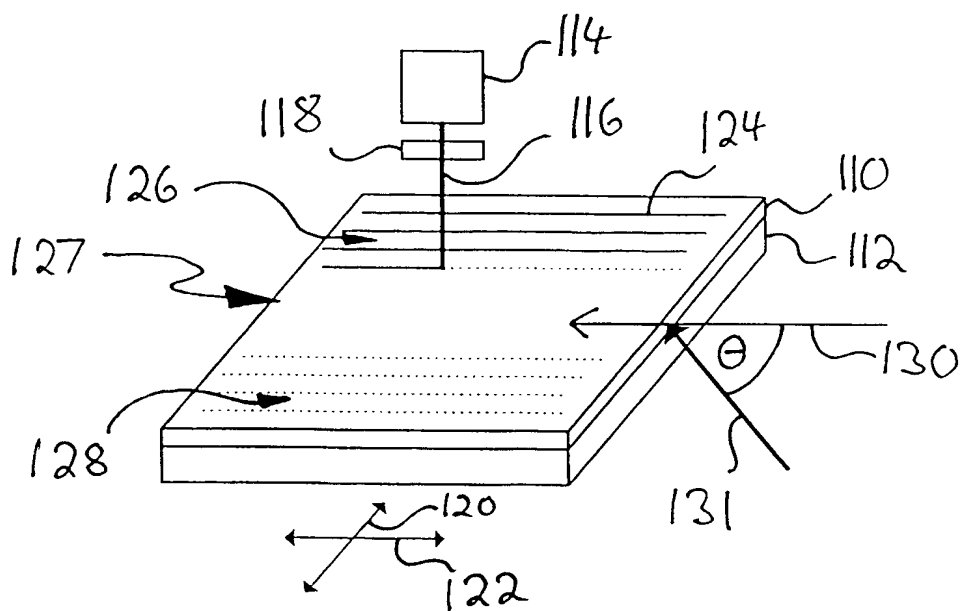


Figure 6

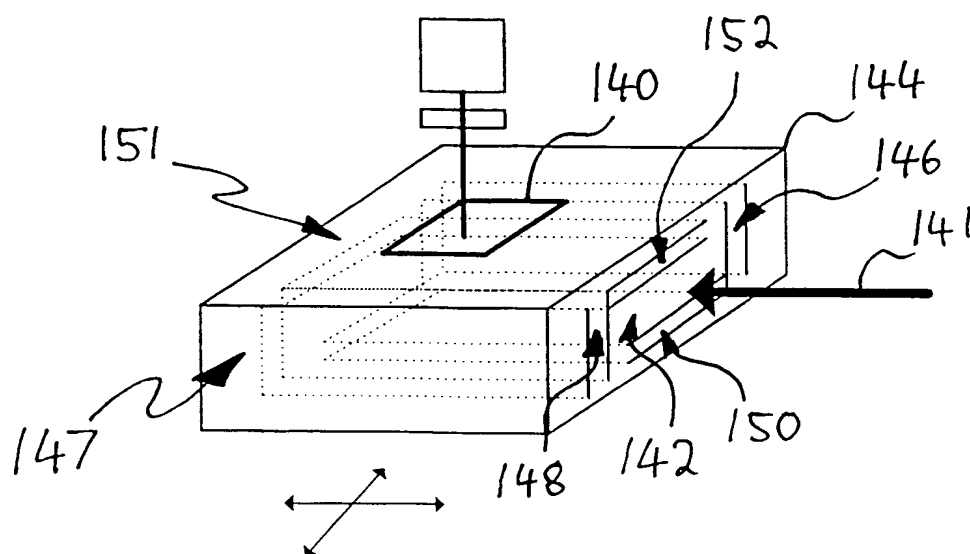
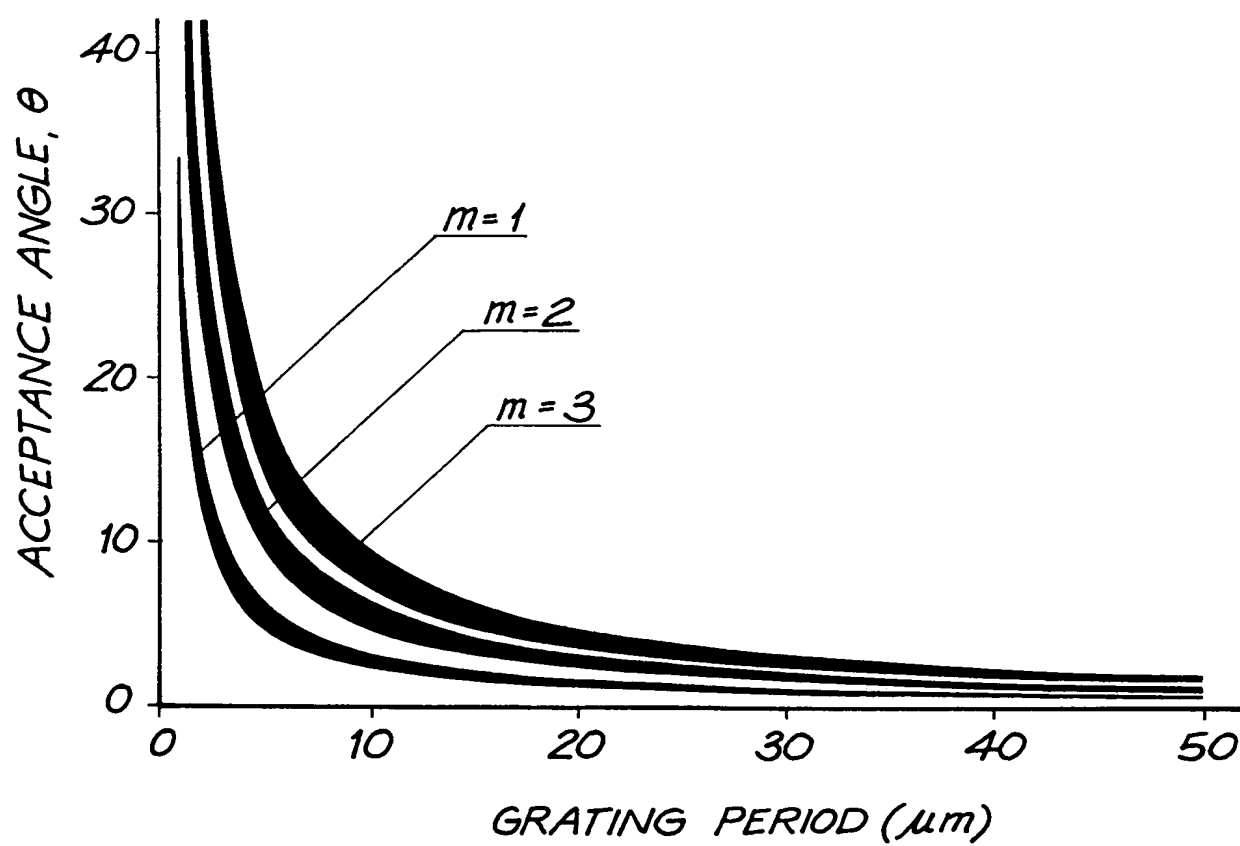


Figure 7

**FIG. 8**

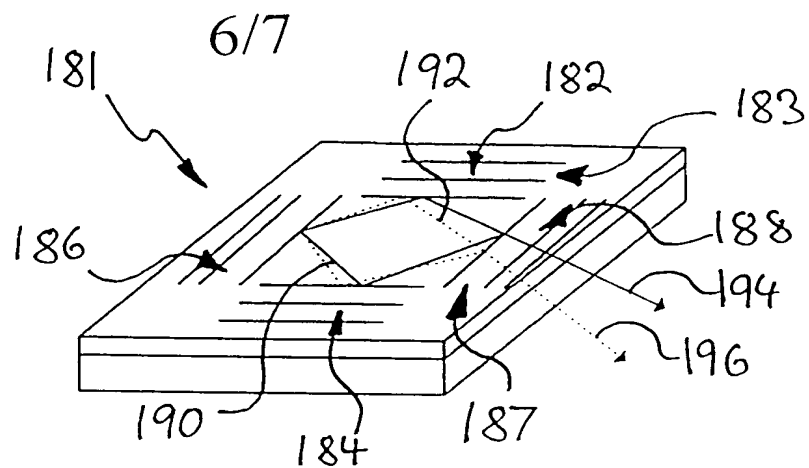


Figure 9

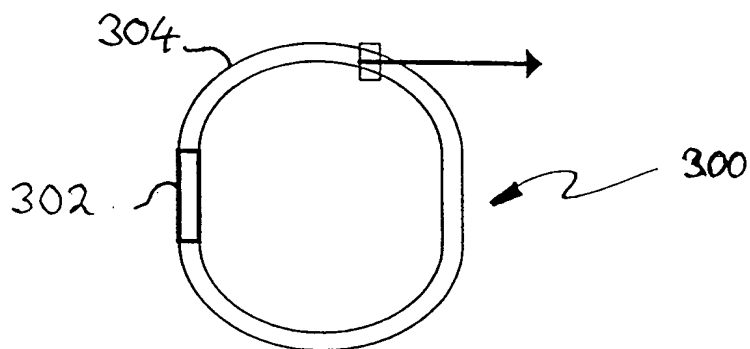


Figure 10

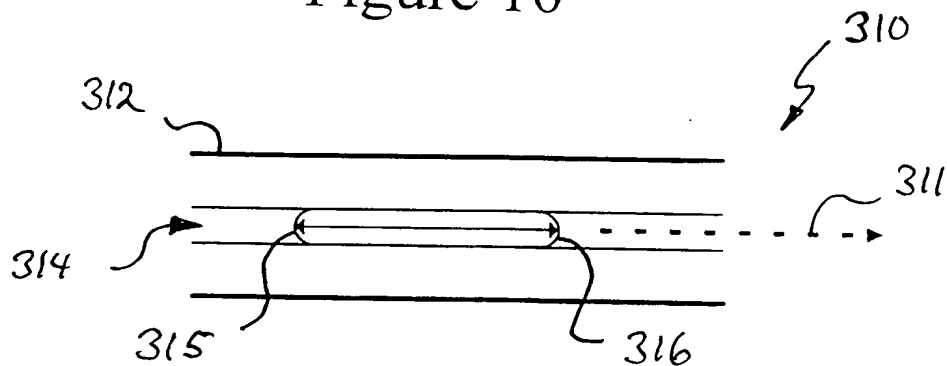


Figure 11

7/7

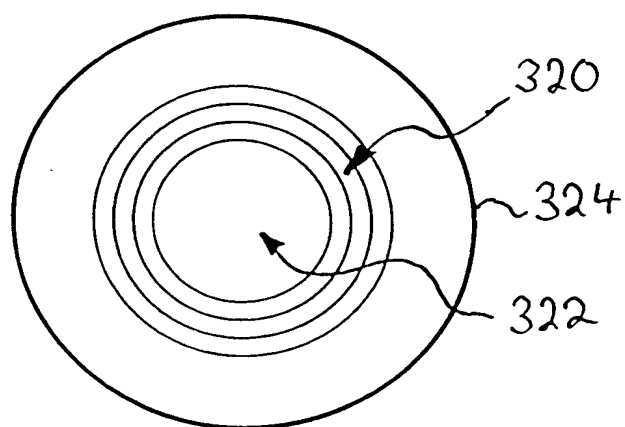


Figure 12

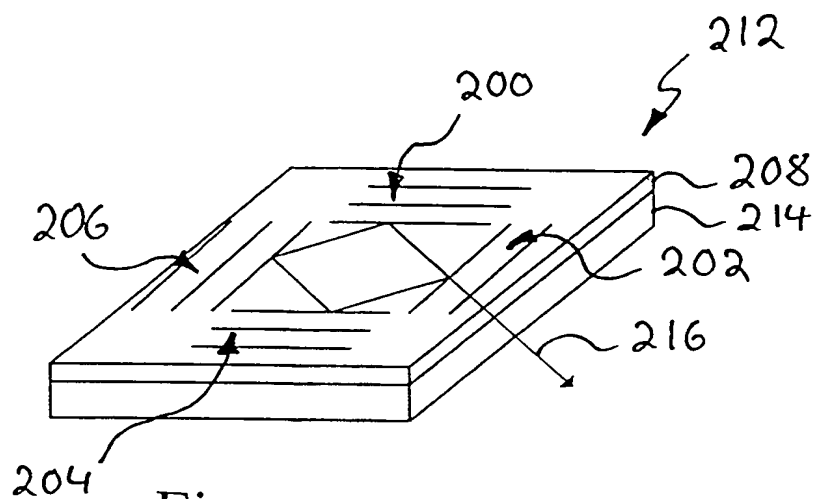


Figure 13

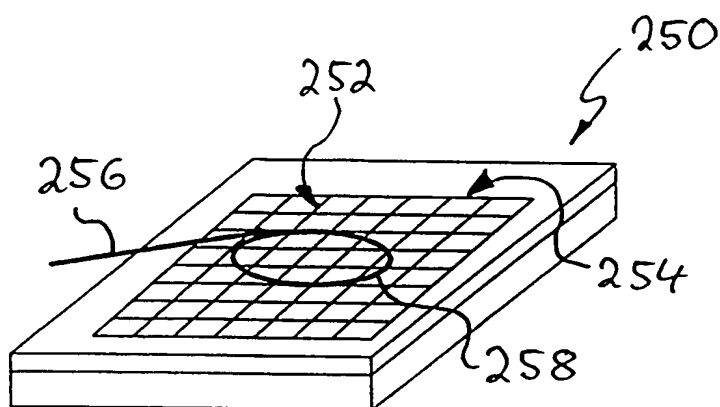


Figure 14

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 99/01000**A. CLASSIFICATION OF SUBJECT MATTER**Int Cl<sup>6</sup>: G02B 6/18, 6/10, 5/26, 5/28, 5/18

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: G02B 5/1C, G02B 6/1C; H04J 14/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT: IPC as above with keywords: (WAVEGUIDE or FIBER or FIBRE) and GRATING and (INCIDEN:  
JAPIO: or ENTER:or ENTRY) and (ANGLE or ANGULAR or BENT or BEND# or BENDING) and  
(WAVELENGTH or FREQUENCY)**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5307437 A (FACQ et al) 26 April 1994 whole document	1-11,16-20
X	US 4874216 A (UTAKA et al) 17 October 1989 First and Third Embodiment, Figures 2, 3, 5	1,6
X	US 4743087 A (UTAKA et al) 10 May 1988 Figures 1, 2	1,3-6

☒ Further documents are listed in the  
continuation of Box C☒ See patent family annex

\* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 December 1999

Date of mailing of the international search report

10 JAN 2000

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE  
PO BOX 200  
WODEN ACT 2606 AUSTRALIA  
E-mail address: pct@ipaustalia.gov.au  
Facsimile No.: (02) 6285 3929

Authorized officer

M.E. DIXON

Telephone No.: (02) 6283 2194

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 99/01000

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2222891 A (STC PLC) 21 March 1990 whole document	1,3,5
X	EP 672924 A (FUJITSU LIMITED) 20 September 1995 Figures 3, 11	1,5
X	EP 310438 A (BRITISH TELECOMMUNICATIONS PLC) 5 April 1989 whole document	1-8,16-18,20
X	Derwent Abstract Accession No: 89-171547/23, Class P81, SU 1418634 A (DERYUGIN) 23 August 1988 abstract	1

# INTERNATIONAL SEARCH REPORT

## Information on patent family members

International application No.  
PCT/AU 99/01000

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	5307437	CA	2064309	EP	506546	FR	2674639
		JP	5142423				
US	4874216	JP	1009414				
US	4743087	JP	60260024				
GB	2222891	EP	365125	JP	2176606	US	5029981
EP	672924	JP	7253519	US	5477363		
EP	310438	AU	24888/88	US	4946245	WO	89/03056
END OF ANNEX							

REC'D 29 DEC 2000

REPORT PCT

Applicant's or agent's file reference FP11653	<b>FOR FURTHER ACTION</b> See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).	
International Application No. <b>PCT/AU99/01000</b>	International Filing Date ( <i>day/month/year</i> ) 12 November 1999	Priority Date ( <i>day/month/year</i> ) 12 November 1998
International Patent Classification (IPC) or national classification and IPC <b>Int. Cl.<sup>7</sup> G02B 6/18, 6/10, 5/26, 5/28, 5/18</b>		
Applicant <b>THE UNIVERSITY OF SYDNEY et al</b>		

1.	This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.																
2.	<p>This REPORT consists of a total of 3 sheets, including this cover sheet.</p> <p><input checked="" type="checkbox"/> This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).</p> <p>These annexes consist of a total of 5 sheet(s).</p>																
3.	<p>This report contains indications relating to the following items:</p> <table border="0"> <tr> <td>I</td> <td><input checked="" type="checkbox"/> Basis of the report</td> </tr> <tr> <td>II</td> <td><input type="checkbox"/> Priority</td> </tr> <tr> <td>III</td> <td><input type="checkbox"/> Non-establishment of opinion with regard to novelty, inventive step and industrial applicability</td> </tr> <tr> <td>IV</td> <td><input type="checkbox"/> Lack of unity of invention</td> </tr> <tr> <td>V</td> <td><input checked="" type="checkbox"/> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement</td> </tr> <tr> <td>VI</td> <td><input type="checkbox"/> Certain documents cited</td> </tr> <tr> <td>VII</td> <td><input type="checkbox"/> Certain defects in the international application</td> </tr> <tr> <td>VIII</td> <td><input type="checkbox"/> Certain observations on the international application</td> </tr> </table>	I	<input checked="" type="checkbox"/> Basis of the report	II	<input type="checkbox"/> Priority	III	<input type="checkbox"/> Non-establishment of opinion with regard to novelty, inventive step and industrial applicability	IV	<input type="checkbox"/> Lack of unity of invention	V	<input checked="" type="checkbox"/> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement	VI	<input type="checkbox"/> Certain documents cited	VII	<input type="checkbox"/> Certain defects in the international application	VIII	<input type="checkbox"/> Certain observations on the international application
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II	<input type="checkbox"/> Priority																
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VII	<input type="checkbox"/> Certain defects in the international application																
VIII	<input type="checkbox"/> Certain observations on the international application																

Date of submission of the demand 31 May 2000	Date of completion of the report 12 December 2000
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer  <b>M.E. DIXON</b> Telephone No. (02) 6283 2194



**I. Basis of the report**

1. With regard to the **elements** of the international application:\*
- ☐ the international application as originally filed.
- ☒ the description, pages **4-12**, as originally filed,  
pages , filed with the demand,  
pages **1-3**, received on **21 November 2000** with the letter of **20 November 2000**
- ☒ the claims, pages , as originally filed,  
pages , as amended (together with any statement) under Article 19,  
pages , filed with the demand,  
pages **13, 14**, received on **21 November 2000** with the letter of **20 November 2000**
- ☒ the drawings, pages **1/7-7/7**, as originally filed,  
pages , filed with the demand,  
pages , received on with the letter of
- ☐ the sequence listing part of the description:  
pages , as originally filed  
pages , filed with the demand  
pages , received on with the letter of
2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.  
These elements were available or furnished to this Authority in the following language which is:
- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).
3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:
- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
4. ☒ The amendments have resulted in the cancellation of:
- ☐ the description, pages
- ☒ the claims, Nos. **18-20**
- ☐ the drawings, sheets/fig.
5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).\*\*

\* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

\*\* Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report

**V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement****1. Statement**

Novelty (N)	Claims 1-17	YES
	Claims	NO
Inventive step (IS)	Claims 1-17	YES
	Claims	NO
Industrial applicability (IA)	Claims 1-17	YES
	Claims	NO

**2. Citations and explanations (Rule 70.7)**

The invention as defined in the independent claims is an optical waveguide structure comprising an optical waveguide having a bend and being formed of photosensitive material and with a grating structure comprising UV-induced refractive index variations and arranged to guide light of a predetermined wavelength around the bend (claim 1); and a method of adapting such a waveguide to guide light of predetermined wavelength around a bend in the waveguide by using UV light to induce refractive index variations in the waveguide such that a grating is formed and is disposed to guide light around the bend (claim 17).

The remaining claims are appended and define further preferred features.

The closest cited art is US 4874216 and relates to an optical branching filter in which a diffraction grating is formed in the cross region of two crossing waveguides to branch light of a particular wavelength to a desired one of the waveguides. However, this document does not disclose a waveguide of photosensitive material nor does it teach a grating structure comprising UV-induced refractive index variations in the waveguide.

None of the remaining citations discloses the features claimed.

Therefore the claims comply with Article 33(2)-(4).